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THE FORECAST OF TEMPERATURE AND WIND IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

by A. D. Chistyakov

-USSR-

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THE FORECAST OF TEMPERATURE AND WIND IN THE UPPER TROPOSPHERE AND LOWER STRATOSPHERE

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The development of aviation in recent years, especially jet-propulsion, has raised before meteorology a series of new problems.

The meteorological protection of flights, which take place in the upper troposphere (VT) and lower stratosphere (NS), has become necessary. For successful flights at great heights, firstly, a forecast of temperature and wind is necessary. In turn, a wind forecast at any height is directly related to a forecast of the pressure field at the given level.

The theoretical works of Soviet scientists - Kibel, Buleev and Marchuk, Obukhov and Monin, - who are engaged in the TSIP, GEOFIAN and GGO, considerably broadened our ideas concerning processes in the troposphere and stratosphere and permitted us to approach the forecast of pressure, temperature, vertical currents and wind at various levels of the atmosphere.

In the beginning of 1951 I. A. Kibel obtained the general equations for the forecast of height changes of isobaric surfaces, temperature and vertical currents at any level of the atmosphere:

(1)
$$\frac{\partial Z}{\partial t} = \frac{r^2 g}{4 \ell P} \int_c^P \left[(Z, \Delta Z) + \frac{\ell}{g} \beta \frac{\partial Z}{\partial x} \right] dp - \frac{R}{g} \left(\frac{1}{P} \int_0^P \frac{\partial T}{\partial t} dp - \int_p^P \frac{\partial T}{\partial t} \frac{dP}{p} \right)$$

(2) $$\frac{\partial T}{\partial t} = \frac{g}{l}(T, z) - (\gamma_a - \gamma) w + (\gamma_a - \gamma)\frac{\partial z}{\partial t},$$

(3) $$w = \frac{g}{l^3 \rho}\left\{ \frac{p-P}{P}\int_0^P \left[(z, \Delta z) + \frac{l}{g}\beta\frac{\partial z}{\partial x}\right] dp + \int_p^P \left[(z, \Delta z) + \frac{l}{g}\beta\frac{\partial z}{\partial x}\right] dp \right\} + \frac{R}{l^2 g \rho}\left[P\int_P^p \Delta\frac{\partial T}{\partial t}\frac{dp}{p} + \frac{p}{P}\int_0^P \Delta\frac{\partial T}{\partial t}\, dp - \int_0^p \Delta\frac{\partial T}{\partial t}\, dp \right].$$

where

z – the height of an isobaric surface

T – temperature

w – vertical velocity

g – force of gravity

$l = 2\omega \sin\phi$ (ω – angular velocity of the earth's rotation, ϕ – latitude)

x, y, p – axes of the coordinates,

the x axis is directed toward the east,

the y axis toward the north

the p axis is upward

t – time

$\beta = \frac{\partial l}{\partial y} = \frac{2\omega\cos\phi}{a_1}$ (a_1 is the radius of the earth)

R – gas constant

γ_a dry adiabatic temperature gradient, equal to $\frac{\kappa - 1}{\kappa}\cdot\frac{g}{R}$

(κ – ratio of specific heats,

C_p – specific heat at constant pressure,

C_v – specific heat at constant volume)

γ – vertical temperature gradient

ρ – density

r – ~~[illegible]~~ radius of the circle, on the circumference of which $\frac{1}{2\pi r}\int_C \frac{\partial z}{\partial t} ds \approx 0$

P – pressure $=$ 1000 mb

$$\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

Thus, we have three equations with three unknowns $\frac{\partial z}{\partial t}$, $\frac{\partial T}{\partial t}$ and W which we must determine. In other words, it is necessary to express the derivatives with respect to time through space derivatives.

For the solution of this system of equations, a numerical method was used by the author, for which the integral through P, which enters in the given equations, was presented by the trapezoid method. Since, at the present time, maps are constructed for only six atmospheric levels (sea level, 850, 700, 500, 300 and 200 mb), then the atmosphere was divided into six layers: 1000-850, 850-700, 700-500, 500-300, 300-200 and 200-0 mb.

During the solution of the given system of equations γ was taken variable with respect to height. In the atmospheric layer 1000-600 mb $\gamma =$ 5 deg/km, from 600-400 mb $\gamma =$ 6 deg/km, from 400-250 mb $\gamma =$ 7 deg/km and above 250 mb $\gamma =$ 0.

Working formulas were obtained as a result of the numerical solution of the given system of equations

$$\frac{\partial z}{\partial t} = a_{10} A_{10} + a_8 A_8 + a_7 A_7 + a_5 A_5 + a_3 A_3 + a_2 A_2 - \\ - \frac{R}{g} \cdot \frac{g}{\ell} \left[b_{10} (T, z)_{10} + b_8 (T, z)_8 + b_7 (T, z)_7 + b_5 (T, z)_5 + \\ + b_3 (T, z)_3 + b_2 (T, z)_2 \right] \tag{4}$$

$$W = \frac{RT}{\ell^2}\left[c_{10}A_{10} + c_8 A_8 + c_7 A_7 + c_6 A_6 + c_3 A_3 + c_2 A_2\right] +$$

(5)
$$+ \frac{RT}{\ell^2}\left\{\frac{K}{\ell}\left[d_{10}(T,Z)_{10} + d_8(T,Z)_8 + d_7(T,Z)_7 + \right.\right.$$
$$\left.\left. + d_5(T,Z)_5 + d_6(T,Z)_6 + d_2(T,Z)_2\right]\right\}$$

(6)
$$\frac{\partial T}{\partial \zeta} = -(\gamma_a - \gamma)\frac{RT}{\ell^2}\left[e_{10}A_{10} + e_8 A_8 + e_7 A_7 + e_5 A_5\right.$$
$$\left. + e_3 A_3 + e_2 A_2\right] + \frac{g}{\ell}\left[f_{10}(T,Z)_{10} + f_8(T,Z)_8\right.$$
$$\left. + f_7(T,Z)_7 + f_5(T,Z)_5 + f_3(T,Z)_3 + f_2(T,Z)_2\right]$$

where
$$A = \frac{r^2 g}{4\ell}\left[(Z, \Delta Z) + \frac{\ell}{g}\beta\frac{\partial Z}{\partial x}\right].$$

The values of the coefficients a, b, c, d, e, f are produced in Tables 1 - 6.

From the analysis of the equations, obtained as a result of the numerical method of solution, it is possible to make a series of interesting conclusions.

I. Vertical motions at the given isobaric surface will be ascending, if in the atmospheric layers below the given level $A > 0$, while layers above this surface $A < 0$. Vertical motions will be ascending also, when $A > 0$ in the lower atmospheric layers and greater in value than in the upper atmospheric layers. Finally, the vertical motions will be ascending if below the given isobaric surface $A < 0$ and smaller in value than A, which is also less than zerò above the given surface.

The vertical motion at the level of the given isobaric surface will

Таблица 1

Values of the coefficients $a_{10} - a_2$

Isobaric Surface	a_{10}	a_8	a_7	a_5	a_4	a_2
1000	0,023	0,054	0,130	0,212	0,159	0,236
850	0,036	0,062	0,122	0,205	0,156	0,234
700	0,054	0,098	0,113	0,176	0,143	0,227
500	0,100	0,175	0,158	0,130	0,084	0,196
300	0,131	0,259	0,275	0,195	0,015	0,046
200	0,129	0,256	0,284	0,260	0,110	—0,019

Таблица 2

Values of the coefficients $b_{10} - b_2$

Isobaric Surface	b_{10}	b_8	b_7	b_5	b_4	b_2
1000	0,070	0,117	0,125	0,093	0,040	0,015
850	—0,010	0,021	0,128	0,096	0,042	0,016
700	—0,009	—0,049	0,040	0,151	0,049	0,019
500	—0,005	—0,030	—0,101	—0,010	0,078	0,029
300	—0,003	—0,010	—0,061	—0,178	—0,103	0,073
200	—0,003	—0,004	—0,040	—0,114	—0,209	0,035

Таблица 3

Values of the coefficients $c_{10} - c_2$

Isobaric Surface	c_{10}	c_8	c_7	c_5	c_4	c_2
1000	0	0	0	0	0	0
850	0,075	0,061	—0,026	—0,035	—0,026	—0,026
700	0,074	0,148	0,031	—0,086	—0,064	—0,062
500	0,074	0,147	0,173	0	—0,151	—0,147
300	0,074	0,148	0,174	0,199	—0,013	—0,345
200	0,175	0,149	0,174	0,198	+0,141	—0,346

Таблица 4

Values of the coefficients $d_{10} - d_2$

Isobaric Surface	d_{10}	d_8	d_7	d_5	d_3	d_2
1000	0	0	0	0	0	0
850	—0,010	—0,014	—0,020	—0,020	—0,009	—0,003
700	—0,008	—0,019	—0,039	—0,048	—0,016	—0,006
500	—0,006	—0,010	—0,049	—0,083	—0,051	—0,020
300	—0,005	—0,002	—0,031	—0,075	—0,061	—0,046
200	0,000	0,000	—0,017	—0,039	—0,060	—0,125

Таблица 5

Values of the coefficients $e_{10} - e_2$

Isobaric Surface	e_{10}	e_8	e_7	e_5	e_3	e_2
1000	1	0	0	0	0	0
850	—0,01	0,95	—0,05	—0,04	—0,02	—0,01
700	—0,01	—0,05	0,94	—0,10	—0,05	—0,02
500	—0,01	—0,06	—0,11	0,81	—0,12	—0,04
300	0,00	—0,02	—0,05	—0,15	0,88	—0,13
200	0,00	—0,01	—0,05	—0,15	—0,32	0,32

Таблица 6

Values of the coefficients $f_{10} - f_2$

Isobaric Surface	f_{10}	f_8	f_7	f_5	f_3	f_2
1000	0	0	0	0	0	0
850	0,06	0,04	—0,04	—0,03	—0,02	—0,11
700	0,06	0,11	0	—0,09	—0,04	—0,02
500	0,04	0,08	0,11	0	—0,11	—0,06
300	0,04	0,07	0,10	0,14	0	—0,22
200	—0,02	—0,03	—0,03	0	+0,08	0,02

be descending for the reverse distribution of A through height.

The calculation of these component vertical velocities for a sufficiently great number of cases showed, that in the stratosphere and troposphere they, as a rule, have a different sign. The level, at which these component vertical velocities are equal to zero, in a majority of cases was situated between the isobaric surfaces 300 and 200 mb and seldom was below the 300 mb surface or above the 200 mb surface.

2. The increase of temperature (heat flux) due to advection, condensation, radiation and insolation etc. is accompanied by ascending motion, while a decrease of temperature (heat outflux) by descending motion. Therefore local changes of temperature are partially compensated by adiabatic cooling or cooling due to vertical motions, which give rise to temperature changes. In the troposphere, where $\gamma \approx$ 5-7 deg/km, the vertical motions which appear due to influx or outflux of heat in the atmosphere reduces the local temperature changes approximately by 0.1-0.2, while in the stratosphere, where $\gamma \approx 0$, they reduce the local temperature changes by 0.7-0.8.

3. Vertical motions depend not only on temperature variations at the level of the given isobaric surface. They also depend on temperature variations in other atmospheric layers. In conformance with this, if a temperature rise is observed in the troposphere, then ascending motion arises not only in the troposphere, but also in the stratosphere; and therefore the temperature in the stratosphere falls. If a temperature fall occurs in the troposphere, then descending motion arises in the stratosphere and a temperature rise occurs.

It is possible to carry out calculations of height changes of isobaric surfaces, temperature and vertical currents by means of the direct

taking of derivatives from the maps of baric topography and substitution of these datainto the corresponding formulas. But since, Z , ΔZ and T often vary greatly with time, then calculations during rapid development of atmospheric processes can not give sufficiently good results. For that reason we prefer the graphical method of prognosis. For the graphical method of prognosis, the baris field at each level is advected along the so called isolines of B , which changes little with time.

Isolines of B do not appear that different from the mean pressure field:

$$B = Z + f \Delta Z$$

where

$$f = \frac{r^2}{4}$$

For the determination of advective temperature changes, auxiliary future maps of the 500 and 300 mb surfaces are constructed. Through the calculation of the height changes of the 300 and 200 mb isobaric surfaces, future maps of these surfaces are constructed. These maps are used for the wind forecast. We shall forecast the gradient wind.

Verification of the proposed method on specific examples showed the following results.

The accuracy of a temperature forecast with a $\pm 3^{c}$ deviation was compiled 78.4% at the level of the 300 mb isobaric surface and 77% at the level of the 200 mb isobaric surface.

The accuracy of a wind direction forecast with a $\pm$ 30° deviation was compiled 86.2% at the level of the 300 mb isobaric surface and 82.2% at the level of the 200 mb isobaric surface.

The accuracy of a forecast of wind velocity with a $\pm$ 30 km/hr deviation

was compiled 80.5% at the level of the 300 mb isobaric surface and 77.8% at the level of the 200 mb isobaric surface.

In figure one the calculated forecast maps of the 300 and 200 mb isobaric surfaces on 12 November 1950 are reproduced, while in figure 2 - the actual maps for this same date.

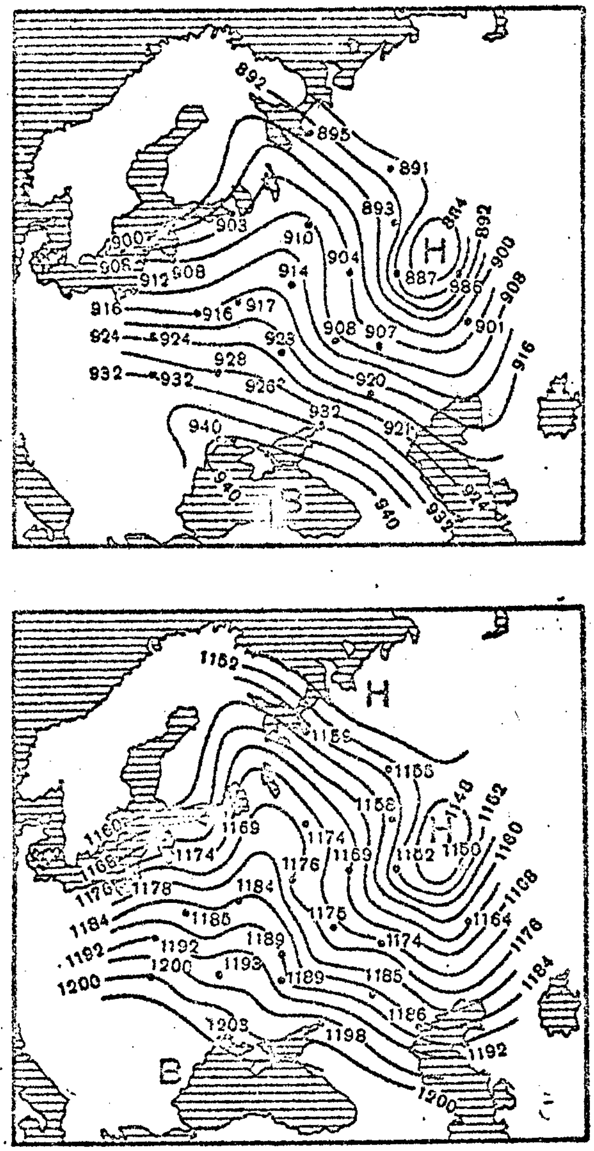

Fig. 1. Precalculated maps of the isobaric surface 300 and 200 mb on 12 November 1950: a - 300 mb; b - 200 mb

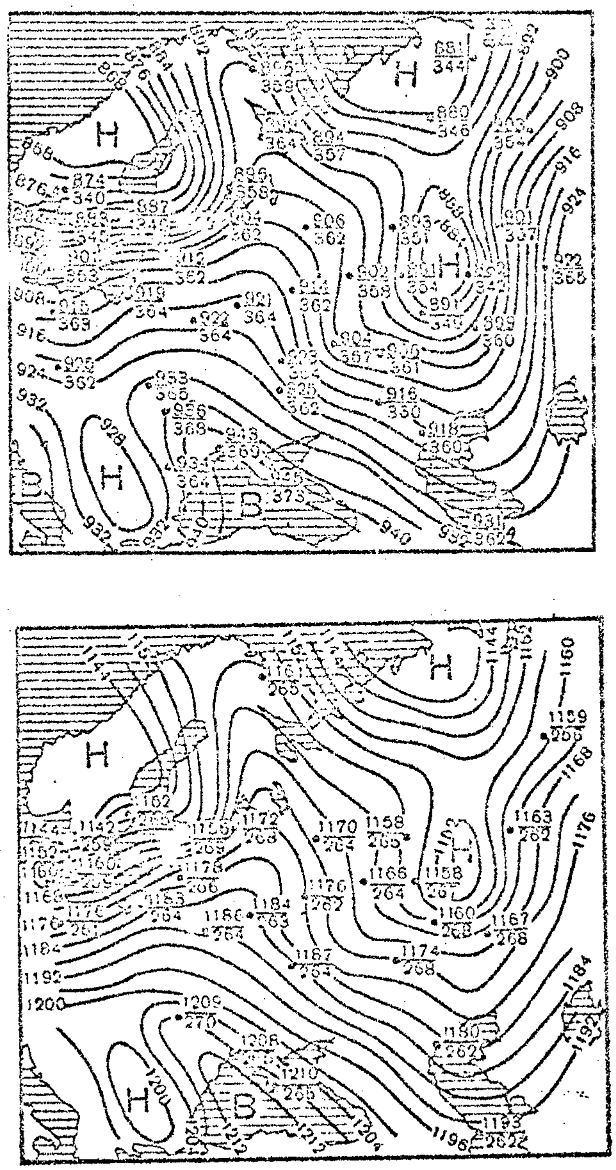

Fig. 2. Actual maps of the isobaric surfaces 300 and 200 mb on 12 November 1950: a - 300 mb; b - 200 mb

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